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Procedia Economics and Finance 1 (2012) 249 – 258

Procedia
Economics and Finance

www.elsevier.com/locate/procedia

International Conference On Applied Economics (ICOAE) 2012

Social Networks: Modeling of Competitive Interaction

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Abstract

Nonlinear dynamic model has been suggested for assessing and predicting the number of social network users. It was shown that Maurer and Huberman's model describes the dynamics of users quite well in the short term. But the appearance of new services and changes in network strategy shift the parameters of system, which significantly affects to users' dynamics in the long-term. So the objective of the study was the modeling of the number of social network users in the long-term. The results have shown that the introduction of variable coefficients allows to describe the dynamics of real data more qualitative – the system can have several stable states of equilibrium; dynamics depends on the competitors' strategies; the final state of the system is sensitive to initial conditions.

Keywords: Nonlinear dynamics, social networks, the number of users

1. Social Networks in the structure of Internet services

Nowadays the Internet has become an integral part of the cultural, economic, social and political life, deepening and extending its variety. The rapid development of information technology in the late 20th century greatly strengthened the position of the virtual space in the service of human interaction [1]. In this century the number of the Internet users reached almost 2 billion people (Table1).

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 doi:10.1016/S2212-5671(12)00029-9

Table 1: World internet usage and population statistics [2]

orld Regions	Population (2010 Est.)	Internet Users	Penetration (% Population)	Growth (2000-2010)
Africa	1 013 779 050	110 931 700	10.9 %	2 357.3 %
Asia	3 834 792 852	825 094 396	21.5 %	621.8 %
Europe	813 319 511	475 069 448	58.4 %	352.0 %
Ukraine	*45 415 596*	*15 300 000*	*33.7%*	*7 550.0%*
Middle East	212 336 924	63 240 946	29.8 %	1 825.3 %
North America	344 124 450	266 224 500	77.4 %	146.3 %
Latin America	592 556 972	204 689 836	34.5 %	1 032.8 %
Oceania / Australia	34 700 201	21 263 990	61.3 %	179.0 %
World Total	6 845 609 960	1 966 514 816	28.7 %	444.8 %

Recent publications, dealt with various aspects of the Internet (development of services, self-organization of users, types of competitive dynamics of web sites, etc.), indicate a high scientific interest to this subject [3, 5, 12-15]. According to the researches, the Internet is unique self-organizing system with complex forms of interaction between participants, which interests are served by diverse services (Fig.1).

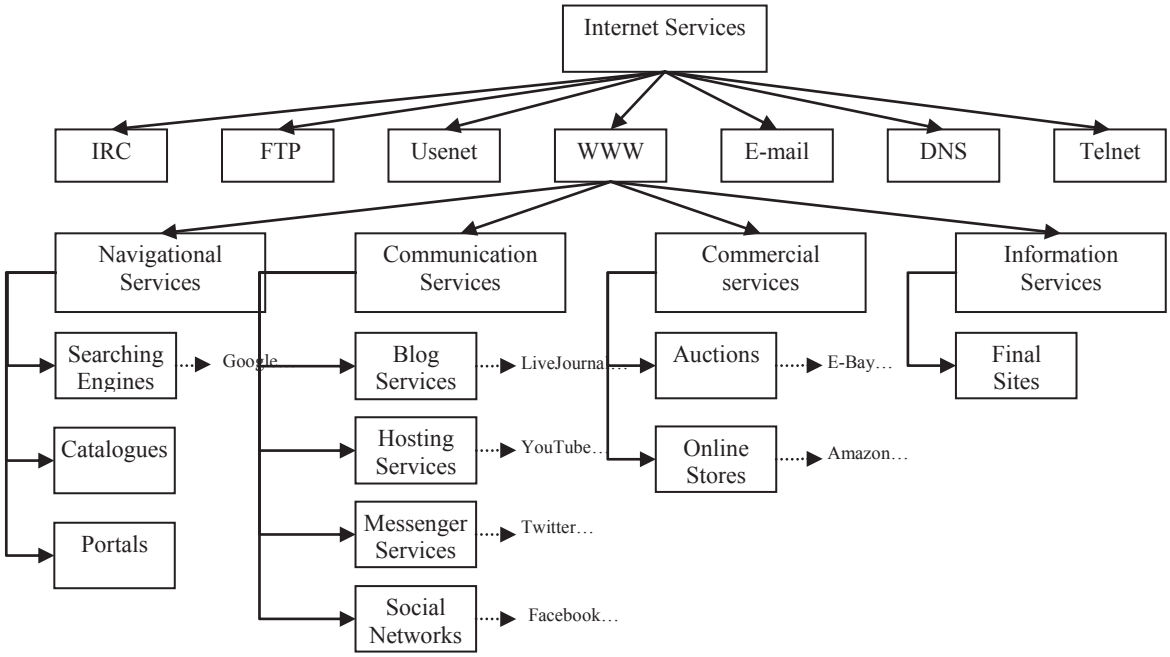


Figure 1: Block diagram of the Internet services

On the service level (Fig.1, line 2) changes are rare – some services are pushed to the background (eg. gopher), some of them continue to develop rapidly (eg. www). The appearance of qualitatively new trends in World Wide Web started to be discussed at the end of 2005, when communication services have come to replace the information and trade services: such monsters of virtual business like E-Bay and Amazon have

been pressed by Web2.0 resources – Facebook, Wikipedia and YouTube (Table 2).

Table 2: Rating of the Internet sites [4]

Rating	2005	2008	2010
1.	yahoo.com	yahoo.com	facebook.com
2.	msn.com	youtube.com	youtube.com
3.	google.com	live.com	yahoo.com
4.	ebay.com	google.com	live.com
5.	amazon.com	myspace.com	wikipedia.org
6.	microsoft.com	facebook.com	msn.com
7.	myspace.com	msn.com	baidu.com
8.	google.co.uk	hi5.com	qq.com
9.	aol.com	wikipedia.org	microsoft.com
10.	go.com	orkut.com	sina.com.cn

As seen from Table 2, among the communication services the social networks are growing most rapidly (it evidenced by the first place of the Facebook in the ranking-2010). Gubanov [5] defines a social network (SN) as a structure consisting of agents' set and specific relations between them. In the Internet this term refers to an interactive multi-user web site based on the Web 2.0, which is used to create and maintain personal and professional relationships between people. Communication service, provided by these networks, connects users by the formal and informal criteria and provides the tools for work, self-expression, and social activity.

Nowadays there are over thousands of the SNs in the Internet; about 100 of them can be called large-scale, the most popular one is the Facebook. The SNs bring together the English-speaking users, and at the same time localized versions develop actively in many countries. Regional networks are also highly popular as well: it is, for example, wer-kennt-wen and studiVZ in Germany, QQ and Xiaonei in China, VKontakte and Odnoklassniki in Ukraine and Russia. In regional markets there is a trend of increasing competition between localized versions of world leaders and regional social networks.

2. Social Networks as a business

From a business point of view, social networks are high-risk venture projects with unclear return on investments. All the e-business risks are common to the social networks: high competition in any market segment; rapid copying of successful technologies; enormous dependence on the team. The main problems of start-ups associated with high cost of "market entry" and the need for continued funding, but most of developers even don't have a clear business model. Therefore, despite the high profitability of the largest social networks (eg. the Facebook), many Web 2.0 projects are still at a loss.

The basic ways of social networks monetization are: 1) advertising, 2) paid services, and 3) the sale of the network. Let's analyze them in details on the example of the most successful Web2.0 project – the Facebook.

2.1. Advertising

Social networks advertising tools are:

1. Banner Advertising. Advertising banners are located on almost every Facebook page. With each banner network gets $ 0.30 per thousand exposures. On this type of advertising the SN earned about 350 million dollars in 2009.

2. Marketplace. Any Facebook user, who posted the ad on the marketplace, can promote it by flyers. The minimum fee is $ 2. This type of advertising gives to the Facebook about 700 thousand dollars monthly.

3. Viral advertising is used for distributing ads on the social graph – from one Facebook user to his

friends.

4. Sponsor's Groups are designed for brand promoting, creating and maintaining its active audience. Sponsor's groups have their own advertising platform; ads of other companies on their pages will not be published. A support cost of such groups is about 100 thousand dollars per month. According to Inside Facebook analytics, network earned about 225 million dollars on brand advertising in 2009.

Due to these services the Facebook revenue is growing rapidly (approximately twice every year (Fig. 2)), which allowed the company to achieve a breakeven in 2008.

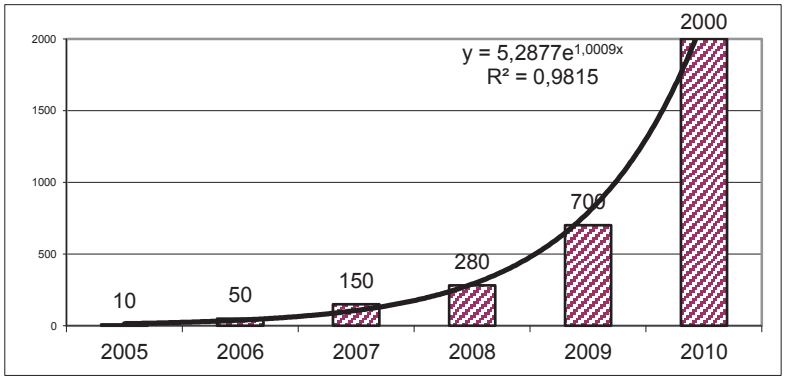


Figure 2: The dynamics of the Facebook revenue, million dollars [7]

According to recent reports, advertisers invested in the social network over three billion dollars in 2010. EMarketer has provided the statistics for the cost of advertising in social networks in the U.S. and around the world (Fig. 3).

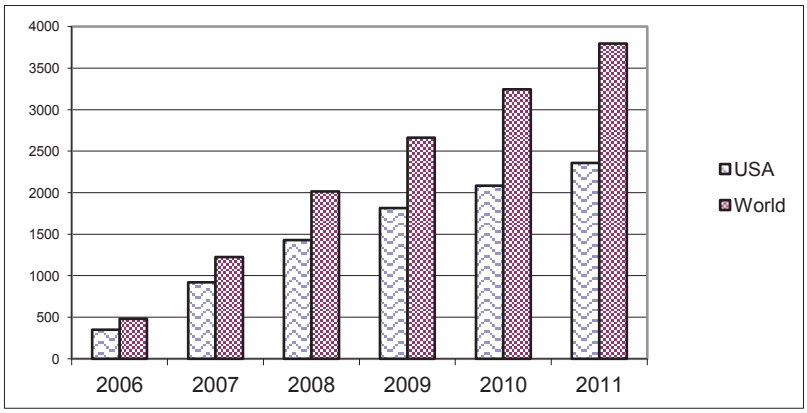


Figure 3: The dynamics of the SNs advertising budgets, million dollars [7]

The success of advertising as a model of the SN monetization is provided by access to major data sources: user's profile (voluntarily left information) and user's behavior (involuntarily left information). Analysis of the profiles allows to show the most precise advertising, to target ads by gender, age, income, profession, etc.

2.2. Paid services

Paid services are sufficiently profitable way of social networks monetization. Most networks offer a variety of paid services – from low-cost ways of users' selection to help in achieving some purposes. For example,

virtual gifts are essential source of the Facebook revenue – about 2 million dollars per month [7].

2.3. Sale of the network

As the social networks are costly venture project, the sale is the one of the most popular ways of their monetization. To do this, start-ups are created, accumulate the users and are sold to large companies that have sufficient resources for the project development and promotion.

The most important pricing factor in all of these schemes is the total number of the SN participants.

3. Quantity estimation of social networks

One of the first who has proposed to evaluate value of social networks was D. Sarnoff. Sarnoff's Law says that network value grows in proportion to the participant's number n. R. Metcalfe (Metcalfe's Law) [9] has detailed this estimate and determined that the value of social networks grows asymptotically as n^2. D. Reed (Reed's Law) [10], assuming the correctness of the previous two laws, added components related to the users' group – 2^n-n-1. Dot-com massive destruction at the end of the 90s made scientists to estimate the SN value more carefully. Metcalfe's and Reed's laws were criticized [11] and there was offered to evaluate the network value as $nln(n)$ (Zipf's Law). Despite the fact that today all these laws have been criticized, the relationship between the number of the SN users and its value is unquestionable; the estimating and forecast the SN users' number is still an urgent task.

3.1. Maurer and Huberman's Model

To estimate the number of the SN users we have used the tools of nonlinear dynamics; as the base of research Maurer and Huberman's Model [12] has been chosen. They proposed to measure the number of website users basing not only on website parameters, but with the influence of other websites, offering similar services (that is very important, taking into account the high competition among start-ups). The model is the following system of differential equations:

$$dx_i / dt = a_i x_i (b_i - x_i) - \sum_{j \neq i, j=1}^{n-1} c_{ij} x_i x_j \quad (1)$$

where x_i – fraction of the i-website users' number ($i=1,n$), a_i ($a_i \geq 0$) – growth rate of i-website, b_i ($0 \leq b_i \leq 1$) – website capacity, c_{ji} ($c_{ij} \geq 0$) – level of competition between websites.

Analysis of the e-statistics, taken by L. Adamik and B. Huberman [13], has shown that small number of websites owned a disproportionate share of traffic and links. An analytical study of (1) for n sites has confirmed their results and showed that there is a strong competition market where the 'winner takes all'. A. Ogus [14] has conducted experiments with agent-oriented model of web-competition, he also has concluded that the network effects often lead to the market monopolization, but in the situation of strong competition among the market leaders, small projects, aimed at a specialized audience, are able to develop successfully.

3.2. Experiments with the Model

We have used model (1) to analyze the dynamics and characteristics of the SNs competition on the example of the three largest networks in Germany – localized version of the world leader (facebook.com) and regional social networks (studivz.net and wer-kennt-wen.de) – Fig. 4.

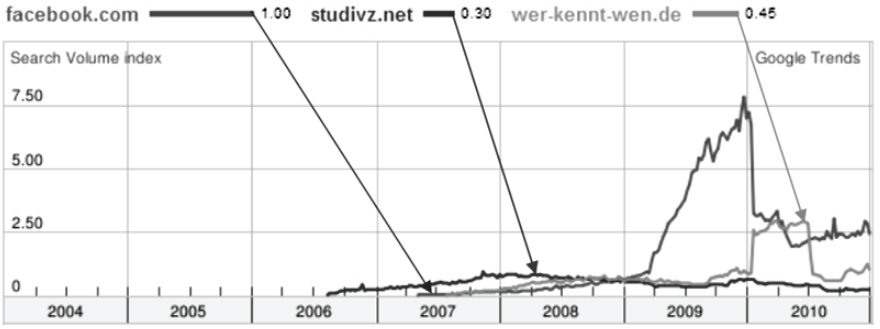


Figure 4: The dynamics of the SNs' users (Facebook, studiVZ, wkw) [18]

Identification of unknown model parameters was being carried out according to the number of unique users since May 2007 to Jan. 2009. As a result, we have got the following system of equations:

$$\begin{cases} \text{studiVZ}: dx_1/dt = -0.1124x_1^2 + 0.1124x_1 - 0.4209x_1x_2 - 0.2457x_1x_3 \\ \text{facebook}: dx_2/dt = -0.3020x_2^2 + 0.0981x_2 - 0.1115x_2x_3 \\ \text{wkw}: dx_3/dt = -0.3834x_3^2 + 0.1852x_3 - 0.8703x_2x_3 \end{cases} \quad (2)$$

Analysis of the system (2) has indicated the absence of competitive pressure from studiVZ on wkw and Facebook ($c_{21} = c_{31} = 0$). It has small growth rate ($a_1 = 0.1124$) and is heavily influenced by their competitors ($a_1 < c_{12}$, $a_1 < c_{13}$). The greatest influence on studiVZ has Facebook ($c_{12} > c_{13}$), which develops under weak competition pressure ($a_2 > c_{21}$, $a_2 > c_{23}$). Wkw growth rate is slightly greater than Facebook ($a_2 = 0.3020$, $a_3 = 0.3834$), but due to the strong competitive effect ($a_3 < c_{32}$), it has a decreasing trend (Fig. 5).

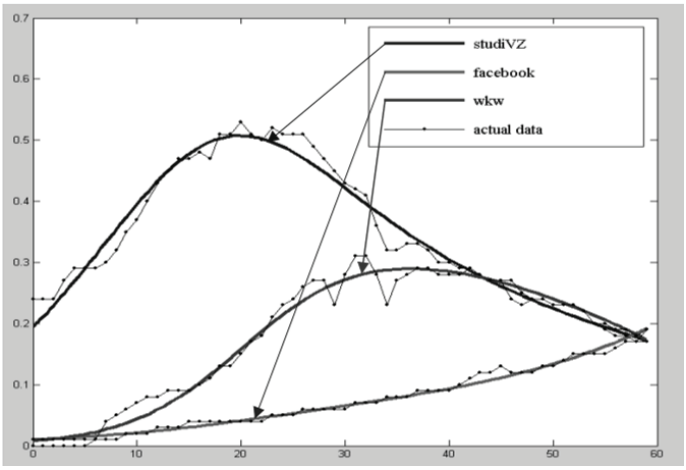


Figure 5: The actual and model data of the SNs' users (Facebook, studiVZ and wkw, May 2007 - Jan. 2009)

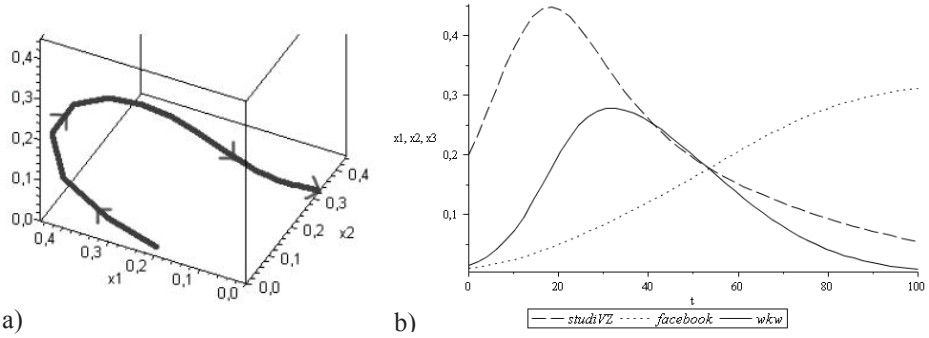
The system (2) has four equilibrium points, three of which are stable (Table 3).

Table 3: Equilibrium points of system (2)

Equilibrium points	Types
(0; 0; 0)	Unstable point
(1; 0; 0)	Saddle

(0; 0; 0.4830)	Saddle
(0; 0.3248; 0)	Stable node

Consider the point (0; 0.3248; 0). It is stable and simulates the situation of 'winner takes all' (Fig. 6-a). It predicts that under certain initial conditions (which correspond to the statistics for May, 2007) Facebook will exclude its competitors and take the leading position, despite strong competition from regional networks, which will lose its audience (Fig. 6-b).



a) b)

Figure 6: a) the phase trend of system (2), x(0)=(0.2; 0.01; 0.015), b) forecast of networks development (Facebook, studiVZ и wkw)

Fig.6 shows that the system with constant coefficients has described the users' dynamics quite well in the short term, but the appearance of new services, changes in network strategy and its competitors significantly affect on the long-term dynamics. The longer modeling interval (May 2007 – Dec. 2010) has significant differences in the actual and calculated data (Fig. 7).

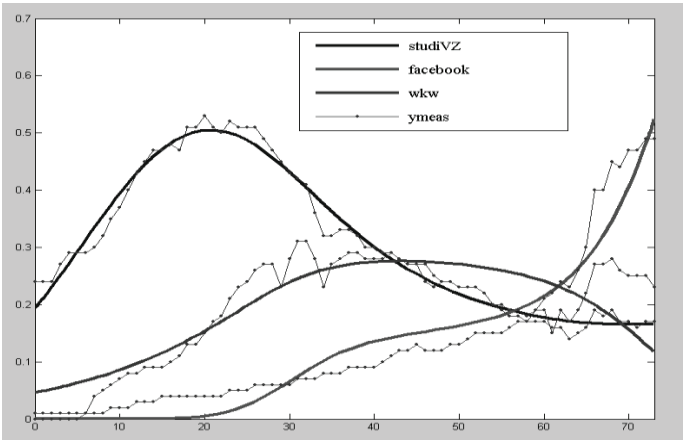


Figure 7: Actual and estimated data for the system with constant coefficients (May 2007 - Dec. 2009)

3.3. Modification of the base Model

Dynamical systems are characterized by the drift of the parameters with the lapse of time, leading not only to change the position of equilibrium, but the nature of sustainability. Therefore, based on the works of M. Eskobido [19] and M. Gernandes [20], we have proposed to model the level of competition between the

networks as a function of the market share as follows:

$$c_{ij} = \frac{k_1 x_j - k_2 x_j^2 + k_3}{1 + x_i x_j},$$

where k_1-k_3 – measured parameters.

After the parameterization the system has taken the following form:

$$\begin{cases} \text{studiVZ}: dx_1/dt = -0.0814x_1^2 + 0.0814x_1 - 0.1020x_1x_2 - \dfrac{1.1919x_3 - 0.0236x_3^2}{1 + x_1x_3} x_1x_3 \\ \text{facebook}: dx_2/dt = -0.1786x_2^2 + 0.1786x_2 - \dfrac{6.8903x_3^2}{1 + x_2x_3} x_2x_3 \\ \text{wkw}: dx_3/dt = -0.1787x_3^2 + 0.1787x_3 - \dfrac{-7.9674x_2 + 8.5990x_2^2 + 2.1273}{1 + x_2x_3} x_2x_3 \end{cases} \quad (3)$$

Analysis of the system (3) has indicated the absence of competitive pressure from studiVZ on wkw and Facebook ($c_{21} = c_{31} = 0$). It has small growth rate ($a_1 = 0.0814$) and is heavily influenced by their competitors. Wkw growth rate is slightly greater than Facebook ($a_2 = 0.1786$, $a_3 = 0.1787$), but due to the strong competitive effect, it has a decreasing trend (Fig. 8).

Figure 8 presents the actual and estimated data for the system with variable coefficients (3) (May 2007 – Dec. 2010).

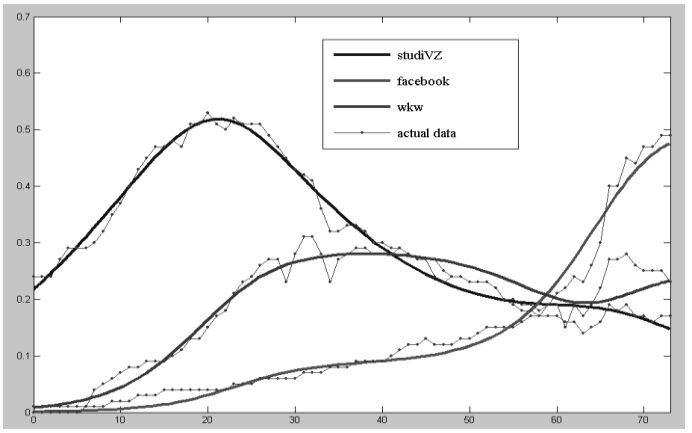


Figure 8: Actual and estimated data for the system with variable coefficients

Equilibrium points of system (3) are presented in Table 4.

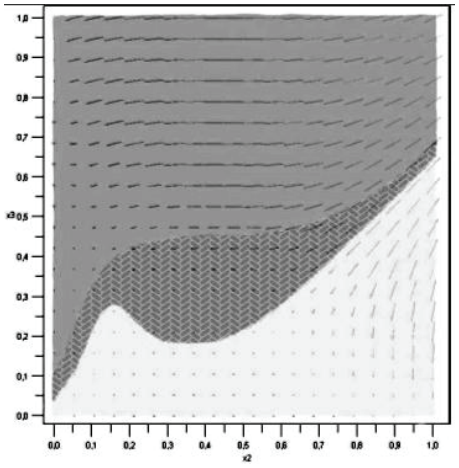
Table 4: Equilibrium points of system (3)

Equilibrium points	Types
(1; 0; 0)	Saddle
(0; 0; 1)	Stable node
(0; 1; 0)	Stable node
(0; 0.5082; 0.2428)	Saddle
(0; 0.3320; 0.2661)	Stable focus
(0; 0.0867; 0.2895)	Saddle

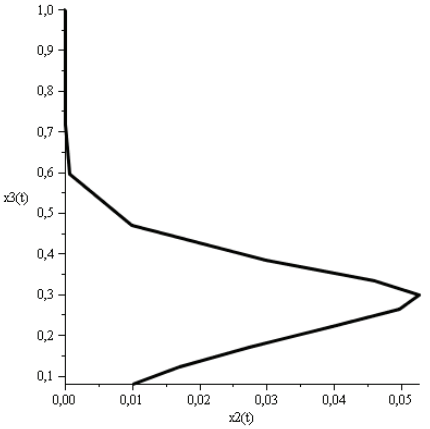
Compared with the system (2) it should be noted the appearance of an equilibrium point, which describes the oscillatory dynamics – (0; 0.3320; 0.2661). It corresponds to a situation of coexistence of the two networks – FaceBook and wkw, which was not observed in a system with constant coefficients. The share of

studiVZ in all stable states is zero, which corresponds to its complete displacement from the market.

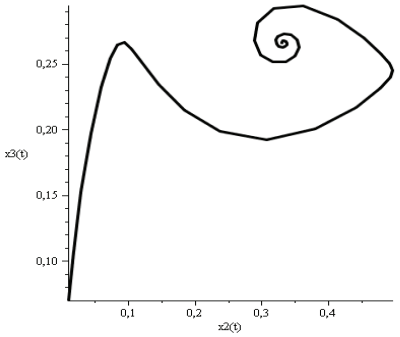
Stable points have their own domain of attraction, and the system falls into one of them depending on initial conditions (Fig. 9).



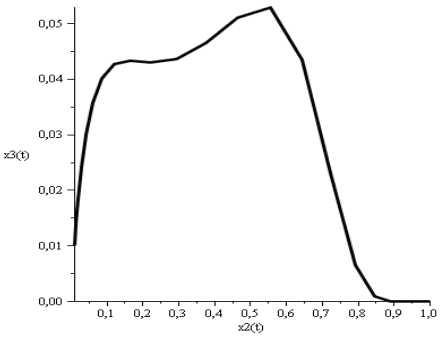
a)



b) x(0)=(0.21; 0.01; 0.08), t=150, stable node (0; 0; 1)



c) x(0)=(0.21; 0.01; 0.07), t=150, stable focus (0; 0.3320; 0.2661)



d) x(0)=(0.21;0.01;0.01), t=100, stable node (0; 1; 0)

Figure 9: a) domain of attraction, b)-d) phase trends of the system (3) at various initial conditions

The analysis of system (3) has showed that the introduction of variable competition coefficients allow to describe the dynamics of real data more qualitative:

1) the system has several stable states of equilibrium;
2) dynamics depends on the competitors' strategies;

the final state of the system is sensitive to initial conditions.

Conclusions

Internet is unique self-organizing system with complex forms of interaction between participants, which interests are served by diverse services. Some services are pushed to the background, some of them continue to develop rapidly, but the appearance of qualitatively new trends in World Wide Web started to be discussed when communication services have come to replace the information and trade services. Among the communication services the social networks are growing most rapidly, nowadays there are over thousands of

the SNs in the Internet.

The most important pricing factor of social networks monetization is the total number of its participants. Despite the fact that a lot of relationships between the number of the SN users and its value have been proposed, the estimating and forecast the SN users' number is still an urgent task.

To estimate the number of the SN users we have used the tools of nonlinear dynamics; Maurer and Huberman's Model has been chosen as the base of research.

It was shown that the system with constant coefficients had described the users' dynamics quite well in the short term, but the appearance of new services, changes in network strategy and its competitors significantly affected on the long-term dynamics. So it has been proposed to introduce of variable coefficients of competition between the networks as a function of the market share as follows.

The results have shown that the introduction of variable coefficients allows to describe the dynamics of real data more qualitative – the system can have several stable states of equilibrium; dynamics depends on the competitors' strategies; the final state of the system is sensitive to initial conditions.

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